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Upper-Atmosphere Density and Temperature

The following report is based on material prepared by Robert Jastrow, Chief, Theoretical Division, Goddard Space Flight Center, National Aeronautics and Space Administration. More detailed treatments appeared in Astronautics, *July 1959, and in the* Journal of Geophysical Research, *November 1959.*

When the IGY began, upper-atmosphere densities and temperatures were relatively well known below a height of about 100 kilometers and less well known between 100 and 200 kilometers. Above 200 kilometers, atmospheric properties could only be extrapolated from lower-altitude data. These extrapolations were uncertain by factors of about 100 at an altitude of 500 kilometers and about 10,000 at 1000 kilometers.

The ceiling on density measurements was raised to 700 kilometers by the first data from the Vanguard I satellite (1958 Beta; see *Bulletin No. 11*), which yielded values at that altitude with an uncertainty factor of only 2. Other satellites before and after Vanguard I filled in the density curve at intermediate altitudes with about the same precision. Analysis of these measurements, combined with rocket data for lower altitudes, has revealed additional features that promise a broader understanding of upper-atmospheric dynamics. The most important among these, perhaps, is evidence that upper-atmosphere properties in the auroral zones are strongly affected by the outer Van Allen radiation belt (see *Bulletins 21* and *30*), and differ very greatly from those of temperate and equatorial latitudes.

Density

Analysis of Satellite Data: Atmospheric density is determined indirectly from satellite tracking data by analysis of changes in the satellite's period of revolution. Atmospheric drag causes a satellite to lose energy continuously during its lifetime. As its energy decreases, the satellite "falls" toward the center of the Earth, reducing its average altitude and, therefore, the time required for each circuit of the globe. Detailed calculations, based on the equations of satellite motion, are used to determine the quantitative relationships between the reduction in orbital period and the average air density in the satellite orbit.

The effect of air drag on a satellite orbit is shown schematically in Figure 1. Since

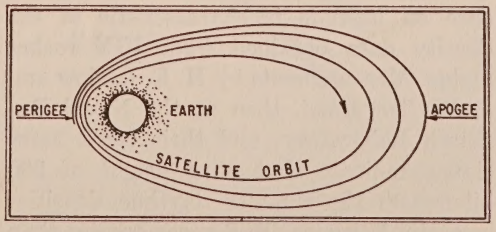

Fig. 1. *Effect of Atmospheric Drag on Satellite Orbit. Drag at perigee reduces altitude of succeeding apogee.*

density falls off very steeply with increasing altitude, the effect of drag near perigee, the lowest point in the orbit, greatly outweighs the effect at other points.

Density Fluctuations: Satellite density data show large fluctuations superimposed on the systematic variations described above. These fluctuations probably result from atmospheric heating produced by streams of energetic particles and radiation from the sun. The sun's surface boils and bubbles actively and continuously, occasionally emitting great gusts of plasma and radiation into the solar system.

L. G. Jacchia, of the Harvard College Observatory, has shown that the seemingly random fluctuations in upper-atmosphere density can actually be correlated with changes in the intensity of 10.7 centimeter radiation from the sun, which constitutes an excellent measure of general solar-surface activity at many wavelengths. In addition, the density fluctuations tend to be repeated every 27 days, which is the sun's period of axial rotation. Thus, it appears that heating and expansion of the upper atmosphere are also produced by radiations and corpuscular streams coming from definite spots on the sun's surface, which appear and disappear every 27 days in the course of solar rotation. In certain instances, the increase in satellite drag has been tentatively identified with the arrival in the earth's vicinity of corpuscular streams following major solar flares (see Fig. 2).

Latitude Dependence: A strong dependence on latitude is characteristic of the density data obtained from IGY rocket flights. Measurements by H. E. LaGow and J. W. Townsend, then at the Naval Research Laboratory, and their NRL associates, indicate that at a height of 200 kilometers the summer daytime densities in arctic latitudes are 6 times greater than corresponding densities at temperate latitudes. (LaGow notes, however, that this apparent latitude effect may not be representative since the temperate region flight was made in 1951, at sunspot minimum, while the arctic flight was made in 1957, at the peak of sunspot activity.) LaGow also found that arctic densities vary with season and time of day: at an altitude of 200 kilometers, the northern atmosphere is twice as heavy during the day as at night and twice as heavy in summer as in winter.

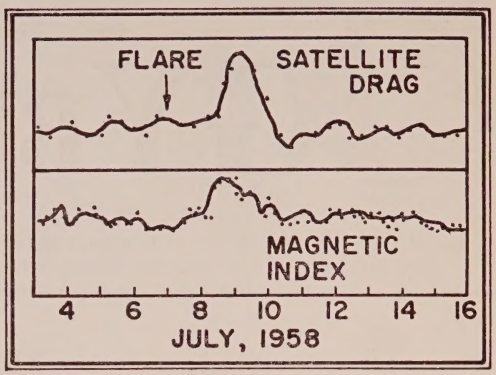

Fig. 2. *Comparison of Satellite Drag Variation and Geomagnetic Disturbance Following Major Flare. (From L. G. Jacchia, 1959.)*

LaGow presents a simple explanation for these daily, seasonal, and latitudinal variations. During the day, solar radiation probably heats the thin upper atmosphere and causes it to expand upward, producing a large relative density increase. This effect should be greater in summer than in winter, and greatest of all during the long arctic-summer day, when exposure to the sun is nearly continuous. These predictions agree with LaGow's observations.

Comparison of Rocket and Satellite Density Data: Satellite results do not show the strong latitude dependence which appears in the rocket data. Since satellite measurements always give the density at perigee, they automatically sample a broad range of latitudes because of the rotation of perigee in the plane of the orbit. In the orbit of Vanguard I, for example, the latitude of perigee moves from 33° N to 33° S

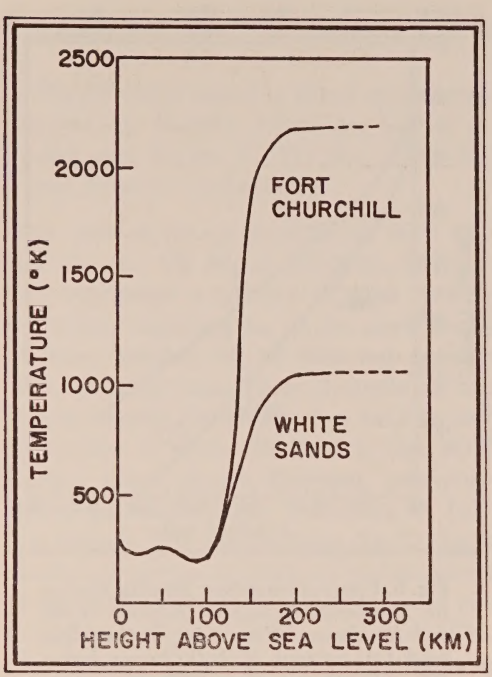

Fig. 3. *Upper-Atmosphere Temperatures Determined from Rocket Data. Fort Churchill is at 59° N, in the Canadian auroral zone; White Sands is at 33° N. (From Horowitz and LaGow, 1958.)*

every 41 days. Although Vanguard I has been in orbit for more than a year, the tracking data have thus far shown no significant changes correlating with latitude variations.

Temperature

Direct temperature measurements have not been made in the upper atmosphere, but temperatures can be determined mathematically from density data on the basis of the relationship between altitude and density.

Using this relationship, LaGow and his associates determined atmospheric temperatures between altitudes of 150 and 200 kilometers over White Sands, New Mexico, and over Fort Churchill, in the Canadian auroral zone. They found that during a summer day the upper-air temperature in the auroral zone is approximately 2000°K (3000°F), while it is a relatively cool 1100°K (1500°F) over New Mexico (see Fig. 3).

Van Allen Radiation Belts: The particles in the Van Allen radiation belts (see *Bulletins 21* and *30*) may provide a further explanation for the differences in atmospheric properties between the temperate and arctic zones. In the Van Allen belts, particles trapped by the earth's magnetic field spiral along the lines of magnetic force. Those in the outer belt are funneled along the lines of force into the arctic and antarctic zones, where the belt dips downward and disturbs the atmosphere, a condition that does not exist at other latitudes.

Interaction between the trapped particles and the polar atmosphere has two major consequences: (i) It appears that the polar aurora results from excitation of the high atmosphere in the Arctic and Antarctic by collisions of air atoms and molecules with the particles trapped in the outer belt; (ii)

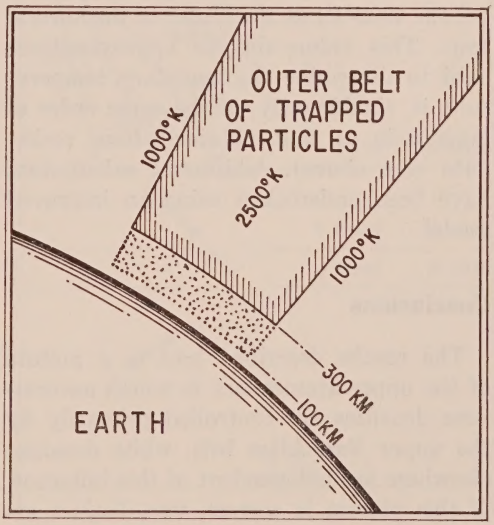

Fig. 4. *Temperature Model Showing Heating of Upper Atmosphere in Auroral Zone by Contact with Particles of Outer Van Allen Radiation Belt. The "horns" of the outer belt approach closest to the earth in the auroral zones* (see Bulletin No. 30).

the atmospheric temperature of the auroral zones is raised by the energy transferred in these collisions.

The theory of upper-atmosphere heating by magnetically trapped charged particles predates the discovery of the Van Allen belts. However, the Van Allen data, supplemented by Sputnik III results and by rocket measurements, provide an opportunity for quantitative tests of this theory. I. Harris and Robert Jastrow constructed an idealized model in which the heating effect of the outer Van Allen layer is confined to a definite region in the auroral zone, with boundaries kept at the "temperate" level of 1000°K (about 1350°F). The rate at which heat is transferred to the air within this zone is calculated from the combination of all rocket and satellite observations of the Van Allen particles. Figure 4 shows a schematic representation of this model. Heat conduction may be computed analytically using the indicated boundary conditions. Harris and Jastrow have shown in this way that the temperature must reach approximately 2500°K (about 4000°F) at the center of the auroral zone. This value, despite approximations used to determine the boundary temperature, is, significantly, of the same order of magnitude as that obtained from rocket data (see above). Additional calculations have been undertaken using an improved model.

Conclusions

The results described lead to a picture of the upper-atmosphere in which auroral-zone densities are controlled primarily by the upper Van Allen belt, while densities elsewhere are independent of this influence. If this picture is correct, two distinct atmospheric models must be considered.

The first, the Temperate-Equatorial atmosphere (curve T-E of Figure 5), is obtained from White Sands rocket data and

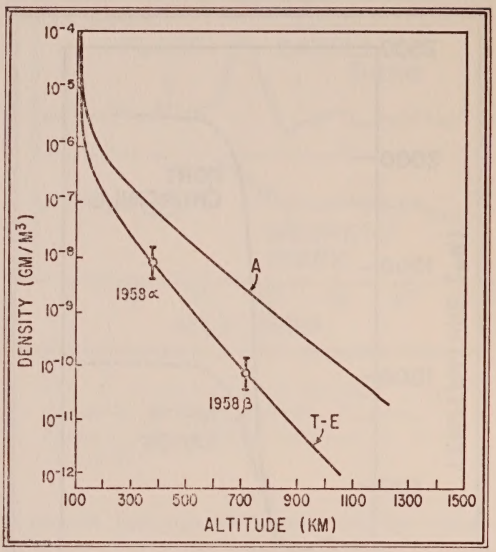

Fig. 5. *Upper-Atmosphere Density Curves for Temperate-Equatorial Regions (T-E) and for Auroral Zone (A). Rocket data used for portions of both curves below 200 kilometers; above 200 kilometers, T-E curve based on atmospheric-drag data for 1958 Alpha (Explorer I) and 1958 Beta (Vanguard I), while A curve extrapolated from rocket data on the assumption of constant temperature.*

computations based on the effects of drag on the orbits of 1958 Alpha (Explorer I) and 1958 Beta (Vanguard I). All density data used for this model were obtained at north and south latitudes no greater than 33°.

The second, the Auroral atmosphere (curve A in Figure 5), is based on rocket observations at Fort Churchill extrapolated above 200 kilometers on the assumption that temperature remains constant. The constant-temperature assumption is based on the LaGow rocket measurements, which indicate little temperature variation between heights of 170 and 210 kilometers.

It is interesting to note that on the basis of the T-E model the oxygen atmosphere will give way to a hydrogen atmosphere at an altitude of approximately 1200 kilometers.

Sunflare II—Rocket Observations of Solar Activity

The following report is based on material supplied by Herbert Friedman, Talbot A. Chubb, and Robert W. Kreplin, of the US Naval Research Laboratory.

As part of its contribution to IGY and IGC-59, the US Naval Research Laboratory conducted a number of solar rocket-astronomy experiments. In the most recent of these, Sunflare II, 12 Nike-Asp rockets were launched from Point Arguello on the Pacific Missile Range between July 14 and September 1, 1959. Sunflare I, the IGY Rocket Flare Patrol Program, was conducted at Point Mugu, California, in July and August 1957 (see *Bulletin No. 7*). Both Sunflare programs represented continuations of the NRL rockoon program of solar observation conducted in the summer of 1956. The Sunflare II series was supported by a grant from the National Science Foundation.

The objective of the Sunflare II experiment was to obtain further direct information about the nature of solar flares—in particular, about the radiations emitted by flares as compared with those emitted by the quiet sun. (*Bulletins 7, 12, 19, 23,* and *29* also discuss this subject.) Of the 12 Sunflare II launchings, eight were completely successful, reaching heights between 130 and 150 miles; in the best flights, data were telemetered continuously for nearly eight minutes. Three of the eight rockets were launched during flares and five were launched when the sun was quiet or only mildly active.

Flares and Related Phenomena

A solar flare is usually seen as a sudden brightening of the sun's surface near a sunspot. A flare reaches its peak brightness—as much as 10 times that of the surrounding photosphere when viewed in Hα, the red light of hydrogen—within minutes, during which a large flare may expand over an area of the sun's surface ranging from 100 million to a billion square miles. The flare's decay is slower, ranging from a half hour to several hours, depending on its size. Visible flares are flat and extend parallel to the sun's surface, remaining essentially stationary throughout their lifetimes. They are three to four times as thick as the chromosphere (the lowest level of the solar atmosphere, extending to a height of about 15,000 miles above the surface), and their uppermost portions reach into the corona. Flares grow outward at speeds only rarely exceeding about 10 miles per second.

Flares are one of a group of phenomena constituting "solar activity," which directly affects the earth's upper atmosphere, frequently interfering with radio communica-

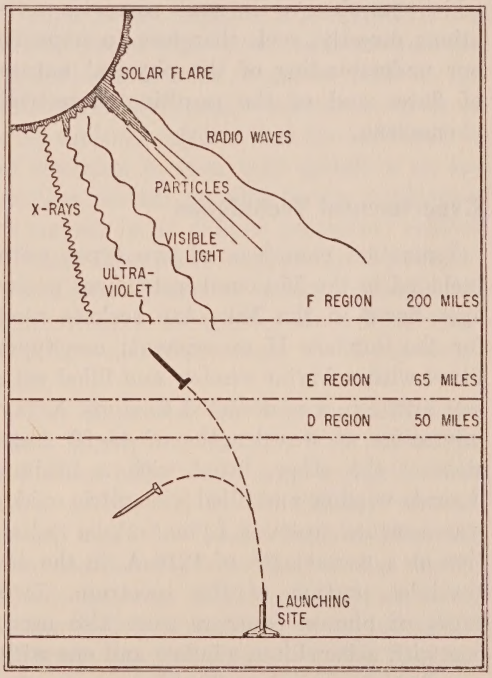

Fig. 6. *The Sunflare Experiment. The two-stage experimental rocket is launched immediately after a flare is reported, penetrating the ionospheric layers and measuring the flare radiations. Comparative wavelengths of the radiation spectrum are suggested schematically.*

tions. The terrestrial effects associated with flares fall into two categories: (i) those occurring almost immediately following the beginning of a flare, such as the radio fadeouts (also termed sudden ionospheric disturbances, or SID), and caused by solar X-rays; and (ii) those beginning about a day later, such as geomagnetic storms, as a result of the arrival at the earth of the high-speed stream of charged particles ejected by the flare.

Although the sun is observed daily in visible light for the purpose of forecasting SID and magnetic storms, many unknowns make accurate prediction extremely difficult. For example, what appears in visible light to be a relatively minor solar disturbance may be followed by great terrestrial disturbances, while an apparently large solar event may produce only minor effects at the earth. Rocket astronomy techniques, which can observe the sun's energetic radiations directly, seek therefore to improve our understanding of the physical nature of flares and of the resulting terrestrial phenomena.

Experimental Techniques

Ionization chambers of two types were included in the 55-pound instrument packages flown in the Nike-Asp rockets used for the Sunflare II experiment: one type, fitted with a Mylar window and filled with dry nitrogen, was designed to study X-ray intensities at wavelengths of 44–60 Angstroms; the other, fitted with a lithium fluoride window and filled with nitric oxide, was designed to study Lyman-alpha radiation at a wavelength of 1216 A, in the ultraviolet portion of the spectrum. Two types of photon counters were also used, one with a beryllium window and one with an aluminum window. The former was designed to cover the 2–8 A region and the latter the 8–18 A region of the X-ray spectrum. Finally, two types of scintillation counters, or proportional counters, were used to study the intensity of "hard," or penetrating, X-rays. One was sensitive to the 2–20 kev range (kev = thousands of electron volts) and the other to the 20–200 kev range. The data obtained by each of these radiation detectors were telemetered to tape and oscillographic recorders mounted in instrumentation vans specially equipped for the rocket astronomy experiments.

Since it was necessary to the success of the experiment that a rocket be launched as soon as possible after the start of a flare, both optical and radio methods were used for flare detection. An NRL team at the Lockheed Solar Observatory in Los Angeles observed the sun's disk in the light of the red line of the hydrogen spectrum, transmitting their observations and flare warnings to the launching site by private telephone. Meanwhile, radio observations of flare effects on the ionosphere were conducted from the NRL van at Point Arguello. These observations of sudden short-wave fadeouts and sudden cosmic-noise absorption, at a frequency of 18 megacycles per second, were reliable indicators of flares of sufficient intensity to cause ionospheric disturbances.

Except in background measurements, an attempt was made to time the rocket launchings—planned on a one-minute count-down basis—so that measurements could be made during the expected peak intensity of the flare. Of the three rockets launched during flares, one reached its peak altitude at the time of maximum intensity of a class 2+ flare. (Flares are classified on the basis of the solar-disk area covered, using a scale ranging from 1 [smallest area] to 3 [largest] with + and — signs indicating positive or negative variations from the average of any class.)

Results and Conclusions

Measurements made during NRL's pre-IGY rockoon program indicated the existence of a background of X-rays in the upper atmosphere with energies perhaps as

high as 50 kev. However, the flux was too small to permit directional measurements that could identify the radiation with the sun. The Sunflare I measurements, during the IGY period, detected intense flashes of 6–7 kev X-rays accompanying solar flares. These flashes were of sufficiently short wavelength (or sufficiently great hardness) to penetrate to the base of the D region of the ionosphere and produce the D-region ionization required to explain radio fade-outs. It was theorized that this production of X-rays in the solar atmosphere could result from heating of the corona above the flare to temperatures greater than 10,000,000° C. The temperature of the quiescent corona is about 500,000° C.

The Sunflare II experiment provided further important information with the discovery of the emission of extremely energetic X-rays during the most active phases of large flares. In the early phases of the three such flares observed, X-rays with energies as high as 90 kev were detected. Moreover, these X-rays were *not* emitted as brief bursts but persisted throughout the full six minutes the rockets were above the absorbing portion of the atmosphere (or about 45 kilometers, the height to which the hardest X-rays penetrated). From start to finish of a flight, it is possible to detect a softening of the spectrum.

During the class 2+ flare mentioned above, the total X-ray flux in the energy range 30–90 kev (0.41–0.14 A) was about 10^{-5} erg/cm^2/sec, decreasing by approximately a factor of 2 for each 5–6 kev increase in energy within this range. This spectral distribution appears to be best explained by the existence of a collection of thermal sources in the solar atmosphere, and the production of 80–90 kev X-rays implies local temperatures—in the vicinity of the flare—of the order of 100,000,000° C.

When the few available measurements of solar X-rays from class 2 and 3 flares are averaged, the following correlations of flux with wavelength are obtained: for wavelengths of 20–100 A, the flux is 2 ergs/cm^2/sec; for 8–20 A, the flux is 3×10^{-2} erg/cm^2/sec; and for 2–8 A, it is 10^{-2} erg/cm^2/sec. The total X-ray flux affecting the E region during the class 2+ flare was roughly twice the quiet-sun value.

The Sunflare II results indicate that high-energy X-rays are a normal solar emission. It appears that even the quiet sun emits a broad spectrum of X-rays extending to very high energies, although the flux is very low, and that the entire spectral range of X-ray emission is enhanced by the intense excitation accompanying a flare.

Possible Origins of High-Energy Solar X-Rays

Several possible mechanisms have been proposed to explain the generation in the solar atmosphere of such high-energy X-rays. X-ray emission is produced by the interaction of high-speed electrons with the coronal gas or with magnetic fields at the sun's surface. The close association of flares with sunspots implies that the acceleration of electrons to such high speeds is an induction process (similar to the production of current in an electric generator) related to rapid changes in magnetic-field strength. The higher the rate of change of magnetic-field strength, the greater the induced electron flow and the stronger the X-ray emission.

The suggestion has been made that the sun's atmosphere contains Van Allen-type radiation belts which trap energetic electrons accelerated in the vicinity of sunspots, and that these trapped electrons generate X-rays. According to one theory, X-ray emission of the strength measured in the earlier rocket experiments (Sunflare I) could be produced by a few hundred relativistic electrons per cm^3 in a coronal region having a magnetic-field strength of only 10 gauss. (Relativistic electrons are electrons moving at sufficiently great speeds —about one-half the speed of light, or faster—so that physical effects predicted

by the theory of relativity become noticeable; the earth's magnetic field at the equator has a strength of about .34 gauss.)

Soviet astronomers observing the strength of solar magnetic fields in flare regions, with a resolution of a few hundred miles, report that flares begin at "null points" in regions of very high magnetic-field gradients. They further report that the flare process wipes out these gradients, thus dissipating the stored magnetic energy. Theoretically, such a mechanism may produce X-rays with energies as high as several million electron volts. The process is similar to the "magnetic pinch" effect scientists are seeking to produce in laboratory experiments to achieve controlled nuclear fusion.

Oceanographic Observations at IGY Wilkes Station, Antarctica

The following material is based on a report by Willis L. Tressler of the US Navy Hydrographic Office, who was Station Scientific Leader at IGY Wilkes Station, 1957–58.

During the 1957–58 IGY scientific program in Antarctica, studies were conducted at US-IGY Wilkes Station on floating ice, currents, tides, and bottom sediments; some hydrographic and bottom-topography survey work was also accomplished. Wilkes Station is situated at 66°15′25″S, 110°31′39″E, in the Windmill Islands on the Budd Coast of East Antarctica (see Fig. 7). The station is at the western end of Clark Island.

The condition and extent of fast ice and floes were observed daily from the aurora tower and, on all except days of extremely poor visibility, movements of ice were photographed with a 16-mm, time-lapse motion picture camera from the same location. A portable tide gage was installed and continuously operated for slightly longer than one complete lunar cycle in the autumn and was again placed in operation in the spring for approximately two months. A series of ten bottom samples was obtained, extending from the shore to deep water in Newcomb Bay. Survey work was accomplished in which the position and orientation of Clark Island and the northern islands were tied in with a point on Holl Island accurately determined by astronomic techniques.

Description of Region

Clark Island is characterized by exposed, rocky areas between large, permanent snow fields, as are the adjoining islands of the Windmill group. (Recent gravimetric and radio soundings show Clark "Island" actually to be a peninsula extending outward from the ice-covered Budd Coast.) In winter, much of the rocky area is snow covered, but during the summer months much rocky terrain is exposed. The snow fields merge inland into a single extensive snow slope which ends in a sinuous shear moraine at an altitude of about 500 feet. (Moraines are features composed of rock material deposited by glaciers; shear moraines are found on the glacier surface and consist of materials that have moved upward along shear planes.) Beyond the shear moraine, the great continental ice sheet extends to the pole, some 1400 miles south.

According to John Hollin, Chief Glaciologist at Wilkes Station in 1957–58, the glacial ice retreated from most of Clark Island approximately 12,000 years ago. Relieved of its load, the land rose about 100 feet and apparently is continuing to rise at the present time, as shown by raised beaches in the vicinity of the station.

Several coves indent the south and southwest shores of Clark Island. Wilkes Station is situated between two of these coves, provisionally named "Ramp" and "Tide Gage" coves (Fig. 7), an especially suitable location for oceanographic observations. The water in the two coves averages about 40 feet in depth and rock pinnacles were observed in several places. From a reconnaissance sounding made in 1957, Newcomb Bay does not appear to exceed a depth of about 270 feet.

In the vicinity of the station, some shoal areas and at least two submerged pinnacles, which are not uncovered at low tide, have been charted. Both of these obstructions are outside the main anchoring area, which was wire-dragged to a depth of 40 feet by the *USNS Greenville Victory* in 1957. The greater part of Newcomb Bay offers a safe anchorage for large vessels and the bottom provides good holding ground. A prominent, permanently ice-covered rock (Fitzpatrick Rock) stands in the middle of the entrance to the bay; there is deep water all around this rock at a distance of not more than about 50 feet.

Weather Conditions

Situated along the coast of East Antarctica, where it could receive the moderating effect of the ocean, Wilkes Station did not suffer the extreme Antarctic weather that other US stations experienced. When open water surrounded the station, temperatures usually remained near about 30°F. The average monthly wind velocity was

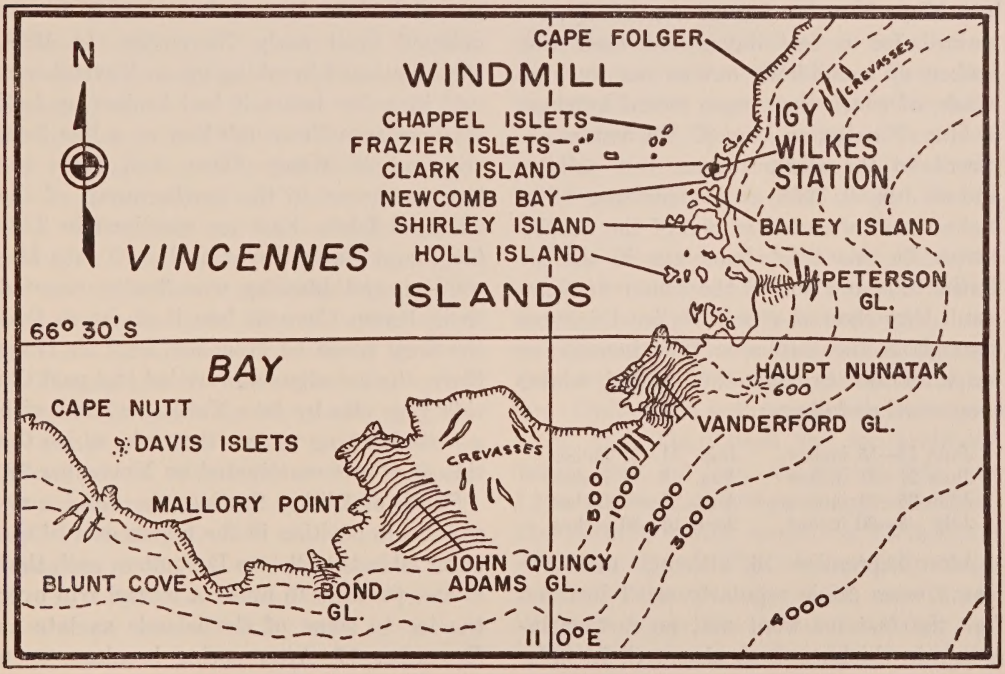

Fig. 7. *Windmill Islands-Vincennes Bay Area of East Antarctica. Approximate position of IGY Wilkes Station is shown. "Tide Gage Cove" is just north of the station, "Ramp Cove" just to the south; "Base Point" is at the end of the peninsula, just west of the station.*

often below that of other US stations and there were many long periods during which there was a complete absence of wind. The frequency of winds exceeding 50 knots and the high peak gusts at other times, however, have earned for Wilkes the reputation of being a windy station.

Sea-Ice Studies

Observations of ice conditions in the portion of Vincennes Bay surrounding Wilkes Station were made daily from the aurora tower or from nearby hills. Open water persisted around the Station, and in Newcomb Bay between Clark and Bailey Islands, until late autumn.

Formation of Fast Ice: As autumn progressed, rocks along the shores of the coves gradually became ice-covered from spray and breaking waves, but fast ice (i.e., attached to shore, etc.) did not form in the coves and for several miles seaward until late May. New ice formed repeatedly, remained for a few days, and then was broken up and blown out to sea by high winds, of which there were record numbers in May. Finally, on May 27, the waters adjacent to the station froze over solidly, and on June 9, 1958, an ice thickness of 14 inches was measured in one of the nearby coves. At this time, holes cut in the ice farther offshore and in the center of Newcomb Bay showed a uniform ice thickness throughout the Bay area. The increase in ice thickness through the austral winter progressed as follows:

June 11—15 inches	July 11—31 inches
June 21—21 inches	Aug. 8—42 inches
June 25—24 inches	Aug. 25—42 inches
July 8—30 inches	Sept. 16—50 inches

After September 16, although measurements were made regularly until just before the fast ice went out, no further increase in thickness was observed. In holes chopped through the ice to measure thickness, ice formed again rather rapidly during the colder months. In a hole chopped on June 20, an ice thickness of 14 inches was measured five days later. During the winter, snow blew in around the shore lines, forming a smooth slope between the bay ice and the rocky hills and snow fields adjoining the coves.

Extent of Fast Ice: Once the fast ice had formed in Vincennes Bay, it slowly grew seaward to what appeared to be a line about two or three miles east of the Frazier Islets, some 10 miles from shore (see Fig. 7). Fast ice never reached the islets during the winter of 1957–58. The fast ice extended considerably beyond the Chappel Islets, however, about five miles west of the station, and continued northward parallel with the shore as far as observers at the station could see. This fast ice to the north remained until late summer, and was still in place when the 1957–58 Wilkes Station party departed, on February 6, 1959.

In 1957, break-up of the ice in southern Vincennes Bay and in Newcomb Bay occurred in late August, but in 1958 it was delayed until early November. In 1958, the ice started breaking up on November 6, and in a few hours it had broken up half way out into Newcomb Bay on a line from the end of Ramp Cove, and from the bay northwest to the northernmost of the Chappel Islets. Fast ice remained in Tide Gage and Ramp coves until well into December, and blasting was finally resorted to in Ramp Cove to free it of ice so that the dory could be launched. In Tide Gage Cove, the ice edge had receded just past the tide gage site by late November, and with a little blasting to free the rocks of ice the tide gage was reactivated on November 28.

South of Wilkes Station, the fast ice remained in position in the region east of the outer islands well into December, such that it was possible to make a weasel trip over the ice to some of the islands as late as December 17. After spring breakup, open water surrounded the station and extended as far as one could see toward the Frazier Islets.

Pack Ice: On some days, a line of pack ice (large accumulation of closely packed floating ice) with numerous bergs could be seen near the northern horizon, having apparently been blown in from farther north or west. Small block and brash and occasional small floes of fairly thin ice were carried past the station by wind and currents from time to time. (A "block" is a fragment of sea ice 6–30 feet in diameter; "brash" is less than 6 feet in diameter; a "floe" may be any sea-ice fragment, but here refers to those greater than about 30 feet across.)

During February 1957, large masses of pack ice moved into Newcomb Bay from the north, seriously interfering with small boat movements. The head of Newcomb Bay remained closed by fast ice, which served as a source for brash and block carried out of the bay by wind and currents. In 1958, the strait between Shirley and Bailey islands remained frozen much longer than it had in previous years.

Conductivity and Salinity of Fast Ice: Electrical conductivity of the fast ice was measured at about the time of each ice-thickness measurement. Melted water from clean ice samples taken 4–6 inches beneath the ice surface were used. The conductivity, hence the salinity, of the samples varied throughout the observation period, showing no particular trend whatsoever. The conductivity level in December was about the same as when first measured on June 11. Throughout the period, salinity varied between 5‰ (parts per thousand) and 8‰. In samples taken from ice hummocks formed above submerged rocks in Ramp Cove, however, salinity decreased steadily until December 4, 1958, six months after formation of the ice, when it was less than 1‰. It is apparent from these studies that brine seeps upward in the ice.

Movement of Cape Folger: Studies of the movement of Cape Folger, an ice point nine miles north of the station, were begun on March 25, 1958, and continued until December 23, 1958. A signal pipe was set in bedrock on the ridge across from the tide gage, and a bench-marked observation point was established on a rock ridge just south of the station's recreation hall. From time to time, a theodolite set up over the bench mark was used to measure the angle between the signal pipe and the face of Cape Folger. On the basis of these observations, it was calculated that Cape Folger moved 130 feet west during the nine-month period at an average daily rate of approximately one-half foot. The rate was not at all constant, but varied from 0.17 to 1.42 feet per day. This rate is slow compared with that of the Vanderford Glacier, which was found by the Wilkes glaciological team (John Hollin, Caspar Cronk, and Richard A. Robertson) to be nine feet per day.

Tide Records

A portable tide gage furnished by the Navy Hydrographic Office was installed on the rocky shores of Tide Gage Cove. Although the tide gage was installed in mid-February 1958, ice conditions made it impossible to obtain continuous and relatively uninterrupted records until early March.

Tidal Measurements: A more or less continuous record was obtained from March 5 through April 19, 1958, in the austral autumn, and from December 15, 1958, through February 2, 1959, in the spring and summer. During the autumn period, the maximum high-tide, based on an arbitrary datum, was 8.2 feet; the lowest tide was 1.7 feet, giving an extreme range of 6.5 feet. The maximum daily range was 5.8 feet, the minimum 0.7 feet. The average daily range for the autumn period was 3.3 feet. It was observed on several occasions during autumn that at neap tides (about midway between the times of full and new moon) there was considerable slack water and consequent lessening of tidal currents.

In the spring and summer period, the maximum high-tide was 7.9 feet, the minimum low tide 1.6 feet, giving an extreme range of 6.3 feet, compared with 6.5 feet for the autumn period. The maximum daily tidal range in the spring-summer period was 6.0 feet, the minimum was 1.6 feet, and the average was 3.5 feet.

Mean Sea Level: Although the tidal observations did not cover a sufficiently long time interval to establish a true mean sea level, the averages were taken as a base for topographic surveys and other work at Wilkes Station requiring at least a tentative approximation of mean sea level. If the average height above the arbitrary zero datum (4.59 feet) for the autumn observation period is compared with the average for the spring-summer period (4.13 feet), a drop of 0.46 foot in mean sea level is found to occur in the latter period.

The occurrence of this phenomenon in other oceanic areas of the world has been pointed out by other workers during the past few years. Walter Munk gives a figure of 0.66 feet (20 cm) for this seasonal difference at Baltimore. (It should be remembered that the seasons are reversed in the two hemispheres; hence, the higher sea-level value occurs in September in the Northern Hemisphere and in March in the Southern Hemisphere.) Munk ascribed this seasonal difference in sea level to actual transport of water to and from the polar regions, rather than to the effect of heating and cooling of the water by solar radiation, evaporation, or other processes, as seems to be the case in low latitudes.

After the fast ice closed the coves and extended for several miles out to sea, a tidal crack developed along the shore. At high tides, water was extruded through this crack out onto the ice, while there seemed to be little vertical movement of the ice. (Other wintering-over expeditions have made limited tidal observations by following the vertical movement of the ice. These results can be only approximate, however, and must be correlated with the rise and fall of open water to obtain more accurate values.)

Currents

Beginning in February 1958, time-lapse, 16-mm moving pictures of ice movements were taken from the aurora tower at Wilkes Station. These studies were made on virtually all clear days when there was open water with ice to photograph. Exposures were made at 30-second intervals at first, and later at intervals of 20 seconds. The film will be examined carefully to determine patterns and trends of the currents near Wilkes Station. At present, however, a few general statements can be made.

Current Patterns: It is readily apparent that strong tidal currents flow in and out of the coves and Newcomb Bay. In Tide Gage Cove, the current is strongest near shore on the side of the cove toward the station. Currents in Newcomb Bay appear strongest near shore, but a considerable current also flows in mid-bay. Currents flowing out of Tide Gage Cove meet currents flowing out around "Base Point," resulting in a large eddy at certain tide stages. On one occasion, two blocks of ice travelling in opposite directions were seen to collide with each other. A few hundred yards off shore, a countercurrent runs in a direction opposite to that of the inshore current. Far out on the horizon, large blocks of ice and small bergs could be seen moving southeastward toward the Midgley Island group.

Origin of Currents: Sometimes, ice movement near shore followed the direction of low cloud formations; most of the time, however, there was no correlation between direction of ice movement and wind direction as indicated by the movement of low clouds. Hence, the currents are most likely of tidal origin. A wind-direction indicator placed in the foreground when future ice-

movement pictures are taken, however, might yield further information on possible relationships between winds and currents in the vicinity of Wilkes Station.

In Ramp Cove, an oscillatory motion of ice blocks was seen at certain tide stages. When the *Magga Dan* (a Danish ship chartered by the Australians) anchored off the south side of Base Point, time-lapse moving pictures were made of her motions while riding at anchor in the hope that they would give some indication of current direction and changes. However, the ship seemed to swing about with little or no regularity, its motions bearing no resemblance to those that might be expected from orderly tidal changes.

Bottom Sediments

In February 1957, while the station was being established, several short cores and bottom-sediment samples were obtained in the deeper waters of Newcomb Bay. Because of considerable variation in the nature of these samples, another series was taken along a line from the shore outward to the deeper waters of Newcomb Bay for comparison and correlation. As soon as the ice had formed in Ramp Cove in June, this second series, of ten samples, was begun at a point about 30 feet from the shore at the head of the cove where the water was 6 feet deep. The series ended at a point where Newcomb Bay is about 225 feet deep.

Description of Sediments: Within the cove, bottom sediments are coarse and relatively well sorted, while in Newcomb Bay the sediment becomes much finer and sorting is poor. (Sorting here refers to degree of uniformity of particle size in the sample, e.g., a well-sorted sample is one of relatively uniform particle size.) None of the pebbles examined appeared to be freshly deposited, but gave indication of long residence in the area. Most pebbles were composed of gneissic, or banded, quartzite, with biotite the most abundant accessory mineral. Some garnet was present, but it was not nearly as abundant as its widespread occurrence in the exposed rocks of the area would appear to indicate. Sand grains were almost all of medium sphericity with angular or subangular configurations. Most quartz grains exhibited a glassy surface texture. Frosted grains in some samples suggest the existence of old beach lines. Quartz was the dominant mineral in the bottom sediments, with feldspar, biotite, hornblende, and garnet occurring in smaller amounts.

Organic Material: Organic remains in the samples varied considerably from station to station, depending on the nature of the bottom sediment. The bottom of Ramp Cove was found to be fairly well covered with both brown and bright red algae having long kelp-like fronds and attached to rocks on the substratum. At the first station, the all-gravel bottom was bare of organic material, while at distances between about 160 and 220 yards out into the cove, some annelid worms and clam-shell fragments were recovered. These appeared to be the only organic remains in the cove proper, and it was not until the deeper water of the bay was reached that other organisms, such as sea cucumbers, brittle stars, and sea urchins, were recovered.

No sponge spicules such as abound in the sediments of the McMurdo Sound region were noted in the bottom sediments of either Ramp Cove or Newcomb Bay. Diatoms were observed only at the last station, well out in the bay.

At the time of spring breakup of the ice, the water around Wilkes was unexpectedly clear, making it possible to photograph the bottom through a few tens of feet of water. It was expected, from experience gained at McMurdo Sound, that by December the planktonic growth would be dense enough to greatly reduce the water transparency, but this never happened and the water remained very clear until the 1957–58 scientific party left Wilkes in early February. (At McMurdo the water was found to be

very clear in early November 1956, but by late December the transparency was greatly reduced and a ½-meter net haul produced a quart jar full of a thick mass of plankton.)

Apparently, the volcanic nature of the exposed rocks at McMurdo Sound offers more easily soluble nutrients, especially silica, in the spring turnover period, resulting in a dense crop of diatoms and probably contributing to the abundance of silicious sponges, which feed on the diatoms. Both of these organisms are very much less abundant at Wilkes, where granitic types of rock provide little in the way of nutrient materials despite considerable runoff of surface water during the summer months.

This same condition was noted by the Soviet investigator, A. P. Lisitzin, in bottom sediments of the Indian Ocean and Pacific Ocean portions of Antarctic waters. Lisitzin reported a scarcity of diatoms near the Antarctic continent, where bottom sediments are composed predominantly of glacial material, while farther north the glacial material decreased and diatoms became predominant in the sediments. Lisitzin also noted that in parts of the Indian and Pacific Oceanic regions submarine volcanoes are associated with zones of diatom oozes.

IGY Bibliographic Notes

This is the eighteenth of a series of bibliographic notes on IGY and IGC-1959 programs and findings. The references are selected largely from a bibliography under preparation in the Science and Technology Division of the Library of Congress. (An interim IGY bibliography, covering the period January 1951–August 1958, prepared by the Library and published by the Academy with support of the National Science Foundation, is available from the Academy, 2101 Constitution Avenue, N.W., Washington 25, D. C., for $1.00. The 64-page volume contains 704 references.)

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